Verification of a Motion Cueing Strategy for Stall Recovery Training in a Commercial Transport Simulator

AIAA-2019-0426

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January 7, 2019

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Introduction

1. Pilots are required to perform full stall recovery training in simulators starting this year
2. Historically, training simulators were not equipped for this
3. Post-stall aircraft models and representative motion cues need to be implemented

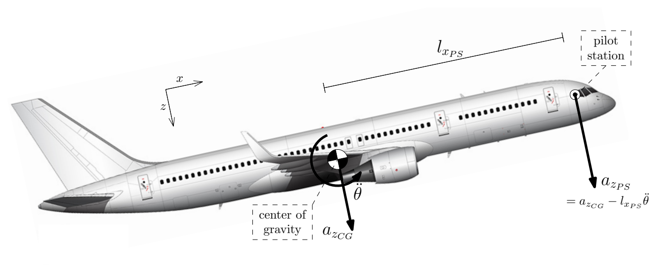
Research Goal

Develop motion cueing strategies for stall recovery training in commercial training simulators

1. Simulators have limited motion space
2. Accelerations at pilot station need to be attenuated
3. Center of gravity linear accelerations require most motion space

Approach

Eliminating the center-of-gravity linear accelerations allows for a significant increase of the fidelity of remaining motion cues



Motion Cueing Strategy

Limitations:

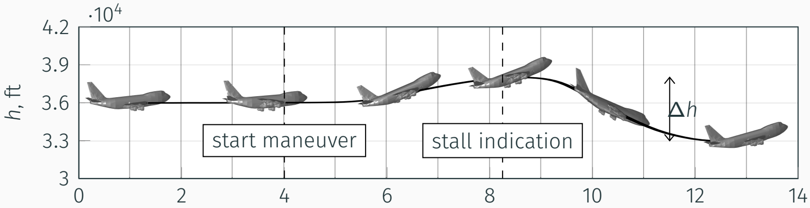
1. No sustained g-loads
2. No deceleration cue
3. No turn coordination

B747-400 Full Flight Simulator

1. Equivalent to level-D certified
2. B747-400 cockpit replica
3. Collimated out-the-window visuals
4. Digital control loading system
5. 54-inch legged hexapod
6. Tabled computer for questionnaire

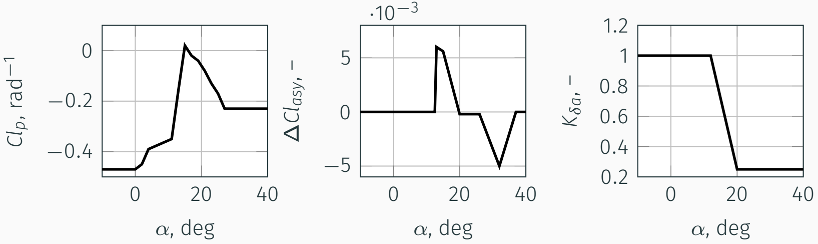
Stall Recovery Task

1. Initially: 36,000 ft, 210 IAS, in the clouds, turbulence
2. Retard throttles to idle and pull up, keeping wings level
3. Continue deceleration through stick shaker until a tone sounds indicating the stall
4. Recover using correct recovery procedure
5. Task evaluation ends when the airspeed is above 210 IAS, the aircraft is climbing, and the wings are level



Modification of a very large, generic, four engine transport aircraft:

1. Roll damping stability coefficient
2. Rolling moment increment due to stall asymmetry
3. Aileron effectiveness gain



Simulator Motion

1. Disabling adaptiveness
2. Gains in equation for pilot station accelerations:

$$a_{ps} = K_t a_{cg} + K_r(\dot{\omega} \times r_{cg-ps} + \omega^2 \times r_{cg-ps})$$

3. Online adjustment of motion parameters

	Degree of Freedom					
	Surge	Sway	Heave	Roll	Pitch	Yaw
High-Pass Gains	0.7	0.7	0.7	1.0	1.0	1.0
High-Pass Break Frequencies	0.6	0.6	0.6	0.3	0.3	0.3
Low-Pass Gains	1.0	1.0	–	–	–	–
Low-Pass Break Frequencies	0.6	0.6	–	–	–	–

Damping ratios (ζ):	0.707
C.G. acceleration gain (K_t):	0.000
Rot. acceleration gain (K_r):	1.000

Experiment Setup

1. Six conditions
2. Latin square design
3. Seven replications per condition (42 runs)
4. Last five replications used for results

Condition	Aircraft Dynamics	Simulator Motion
B1	baseline	no motion
B2	baseline	baseline
B3	baseline	enhanced
E1	enhanced	no motion
E2	enhanced	baseline
E3	enhanced	enhanced

Experiment Setup

1. Eight commercial airline pilots
2. Four different airlines
3. Left or right seat
4. No specifics about conditions
5. Post-run questionnaire

Experiment Setup

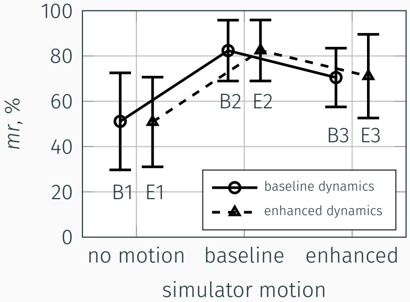
Dependent measures:

1. Four subjective questionnaire responses:
   1.1 Motion rating
   1.2 Motion usefulness question
   1.3 Wing roll-off noticeability question
   1.4 Stall recovery in actual flight question
2. Six objective performance measures:
   2.1 Maximum roll attitude
   2.2 Altitude loss
   2.3 Minimum load factor
   2.4 Maximum load factor
   2.5 Number of secondary stick shakers
   2.6 Maximum airspeed

Results

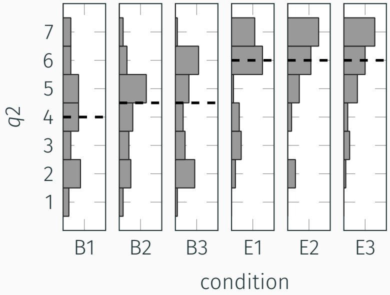
Motion rating:

1. No significant differences
2. Enhanced motion rated lower?



Roll off question:

1. Significantly higher with enhanced dynamics



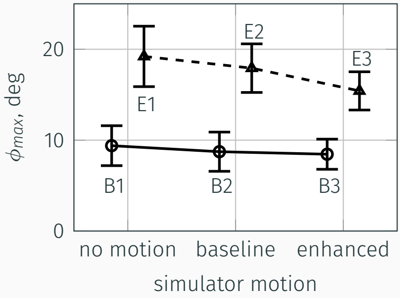
Results

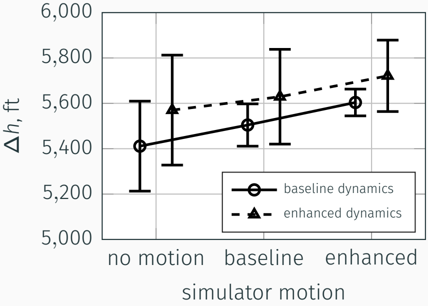
Maximum roll:

1. Significantly higher with enhanced dynamics
2. Significantly lower with higher fidelity motion

Altitude loss:

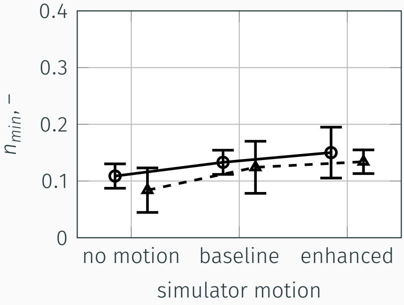
1. No significant differences





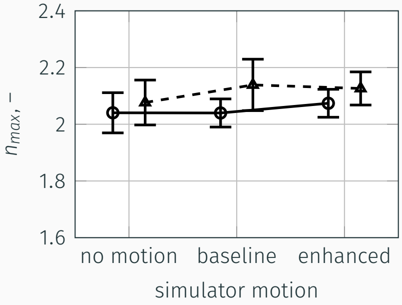
Minimum load factor:

1. Significantly higher with enhanced motion



Maximum load factor:

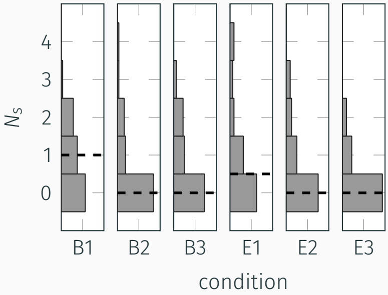
1. No significant differences



Results

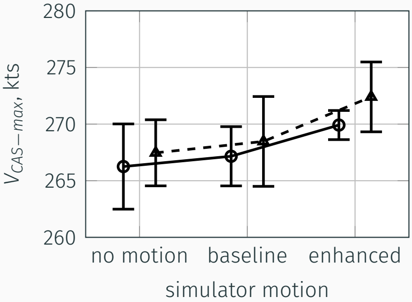
Additional stick shakers:

1. Significantly lower with enhanced motion



Maximum airspeed:

1. Significantly higher with enhanced motion



Conclusions

1. Aircraft dynamics and motion introduced significant differences
    1.1 Motion helpfulness question
    1.2 Maximum roll
    1.3 Additional stick shakers
    1.4 Minimum load factor
    1.5 Maximum airspeed
2. Better stall recovery performance with enhanced motion
3. Relatively minor enhancements to potentially improve training

Questions?

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